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Applications of Radar in Highway Design, Construction and Maintenance

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Applications of Radar in Highway Design, Construction and Maintenance

Author(s):	C.R. Carter, T. Chung, Communications Research Laboratory, McMaster University
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Ministry Contact:	Mr. Tony Masliwec (416) 235-4689
Abstract:	The use of radar in the areas of air traffic control, weather monitoring and ship navigation are all well documented in the literature of the past 30 years. Radar provides the user with a tool that can be exploited in the areas of remote sensing and non-destructive testing. Research studies were undertaken to investigate the possibility of using radar for remote sensing applications in the areas of highway design, construction and maintenance. This report provides an overview of the results of the investigation as related to the areas of site conditions, quality assurance in construction, weather monitoring, road surface conditions and traffic characteristics.
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C.R. Carter
Associate Professor
Communications Research Laboratory
McMaster University

T. Chung
Research Associate
Communications Research Laboratory
McMaster University

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1201 Wilson Avenue
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Telephone: (416) 235-3480
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Executive Summary

Recent studies to identify methods of determining the condition of asphalt-covered bridge decks have shown ground penetrating radar to be a powerful investigative tool. The Communications Research Laboratory became involved in the program in the spring of 1983 through a contract with the Ministry of Transportation and Communications which led to the computer processing of the impulse radar data using an HP 1000 minicomputer. A follow-on project in 1984 lead to the development of the DART, a system combining the impulse radar, a fifth wheel for measuring distance and a microcomputer based data acquisition system for processing the data.

The objective of this study is to examine the Ministry activities in the design, construction and maintenance of highways to determine if there are other applications where radar could be used advantageously. In addition, the study is intended to identify the benefits which may accrue from reduced costs or from technical improvements in the quality of data or speed of data collection.

The report is divided into four major sections plus Introduction, Conclusions and Appendix. Section 2 provides a practical introduction to the principles of radar and how it can be applied in a general sense to the Ministry environment. Section 3 deals with the general application of radar in the Ministry milieu. Section 4 examines in detail those areas of specific interest with details of how the implementation be accomplished and the probability of success. The problem is divided into four main categories which are:

1. Geophysical Site Conditions
2. Pre-engineering, Quality Assurance and Maintenance
3. Weather Monitoring and Road Surface Conditions
4. Traffic Characteristics

Each of these is examined in detail to determine how radar can be applied to the problem, whether there are any obvious problems in implementation and what the probability of success is likely to be.

An overall chart is provided which indicates the most promising of the applications. In particular, it is found that there is a very high chance of success in the first two items;

namely, Geophysical Site Conditions; and Pre-engineering, Quality Assurance and Maintenance. One of the attractive features of each of these areas is that the in-house radar system can be used in most instances. In many of the applications, the procedure would be much like the present DART operations on bridge decks but with additional signal processing required.

For the remaining two areas; namely, Weather Monitoring and Road Surface Conditions; and Traffic Characteristics, it appears that radar is not well suited for the application with the exception of monitoring traffic speed. In addition, the presently used DARTS would require extensive modification or operation in cold weather, neither of which is recommended.

It is concluded that further studies should be conducted in these identified areas to extend the basic understanding. In particular, a method of testing for faults in columns, beams and piers is discussed which may prove interesting.

1/ Introduction

Recent studies to identify methods of determining the condition of asphalt-covered bridge decks have shown ground penetrating radar to be a powerful investigative tool [1-2]. The Communications Research Laboratory became involved in the program in the spring of 1983 through a contract with the Ministry of Transportation which led to the computer processing of the impulse radar data using an HP 1000 minicomputer [3].

It was recognized at the conclusion of the contract that improved performance and capability, and cost savings could be realized by employing a data processor specifically tailored for the task. This processor, called the Deck Assessment by Radar and Thermography (DART) system, has been developed as a result of a second contract which was awarded in 1984 [4]. Results using the DART indicate that the system is capable of processing signals from structures other than bridge decks provided that the radar has the capability of giving sufficient resolution and detection. Thus, the DART could then provide considerable savings in time and effort while giving far more detailed analysis.

The objective of this study is to examine the Ministry's activities in the design, construction and maintenance of highways to determine if there are other applications where radar could be used advantageously.

The study will identify potential applications of radar. Benefits may accrue from reduced costs or from technical improvements in the quality of data or speed of data collection.

1.1/ Objectives

The project has been divided into four separate tasks described here.

Task 1

Review domestic and foreign practice and research findings with respect to the application of radar to highway work. Also, review the possibility of using radar in its different forms as applied to the goals of the Ministry. This is to be accomplished by conducting a thorough literature search by computer to collect all relevant published material.

Task 2

Based on the findings of Task 1, investigate how these different forms of radar can be applied to possible needs of the Ministry. Evaluate the properties of materials commonly found in the Ministry environment and determine the usefulness of radar in this context.

Task 3

In conjunction with the Ministry staff, examine the potential applications of radar identified in Tasks 1 and 2 from the stand-point of practicality. The areas to be examined include:

1. Geophysical Site Conditions
2. Pre-engineering, Quality Assurance and Maintenance
3. Weather Monitoring and Road Surface Conditions
4. Traffic Characteristics

Task 4

Prepare a final report to include the findings of Tasks 1, 2 and 3 and to clearly identify which are potentially the most cost-effective applications for radar in the Ministry work.

1.2/ Overview of Report

Section 2 provides a practical introduction to the principles of radar and how it can be applied in a general sense to the Ministry environment. Section 3 deals with the general application of radar in the Ministry milieu. Section 4 examines in detail those areas of specific interest with details of how the implementation be accomplished and the probability of success. Section 5 comprises Conclusions and Recommendations for further research.

2/ Fundamentals of Radar

2.1/ Radar

The word 'radar' is an acronym which stands for RAdio Detection And Ranging. Most often, radar is thought of as being a method used for detecting and guiding aircraft in vicinity of airports, as illustrated in Figure 2.1. However, there are myriad applications which include [5]: monitoring weather conditions, police traffic control, insect detection, crop evaluation, asteroid detection, navigation, hazard detection, fault detection, astronomy, clear-air turbulence detection, missile guidance, and many others.

Essentially, the method is dependent on the use of electromagnetic waves formatted in different ways which are transmitted and received by means of one or more antenna(s). Since the formatting can take many different forms and a large number of different antennas can be employed, there is a wide range of types of radar each with its own special purpose.

It is noteworthy that most radars are tailored to meet a certain specific need. Very seldom is any attempt made to produce a 'generalized' radar which can perform many functions. The reason for this is the inflexibility of the high power transmitters and antenna assemblies which comprise the most expensive portions of the radar system. The five main considerations which govern most radars are:

1. electrical properties of the target and propagation medium;
2. the transmitted power level;
3. the antenna;
4. the receiver system;
5. the use of pulsed or continuous transmission.

The following sections provide a brief discussion of these areas.

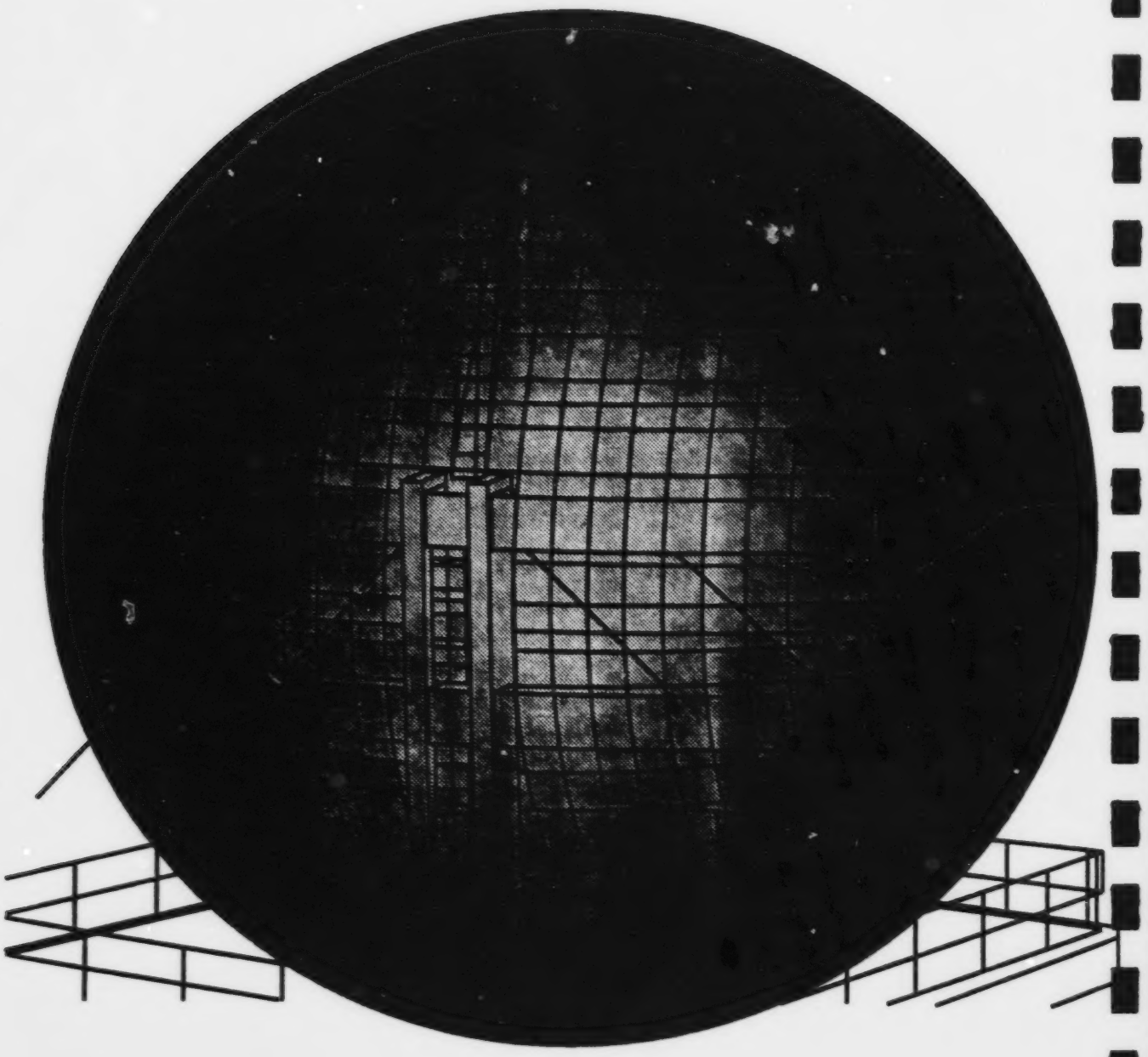


Figure 2.1/ Airport surveillance radar

2.2/ Target Properties and Propagation Medium

Two important factors relating to the target are its size and its electrical properties. Generally speaking, the bigger the target is, the easier it is to detect. There are other considerations such as the shape and the orientation with respect to the radar wave but usually the user has no control over these conditions.

The electrical properties of the target are of paramount importance. If detection of an object is desired, then it is necessary for the object to have electrical properties considerably different from those in the surrounding medium. For example, the detection of aircraft by radar is only possible due to the fact that the aircraft contains metal (which is a good conductor) as opposed to the surrounding medium, air, which is a poor conductor.

In more general terms, there are three properties of all materials which describe the electrical behaviour. These are [6]: the conductivity (σ), the permittivity (ε) and the permeability (μ). The first is related to the ability to conduct current and divided into three classes of materials: conductors, such as metals; semi-conductors, such as transistors; and non-conductors, which include almost all other materials. The second property, permittivity, is related to the ability of materials to store electric energy and all materials exhibit some capacity in this regard. The third property, permeability, relates to the magnetic properties of materials and is significant in only a few cases such as iron, nickel and cobalt. Thus, in general, every material can be classed in terms of these three parameters and differentiation based on electromagnetic waves is possible only when the target has one or more of these three properties significantly different from the surrounding media. Tables of these parameters for some common materials are provided in Figure 2.2.

The following rules-of-thumb can usually be applied to any radar problem:

1) The medium through which the wave propagates (on its way to the target) must have low conductivity and low loss, and should have values of permittivity and permeability no more than 10 to 100 times that of air (if the distance traveled is significant with respect to the wavelength of the radar signal). In addition, the medium should be relatively uniform with no sudden changes in its electrical properties.

(a) Conductivity

Substance	Type	Conductivity $\Omega\ m^{-1}$
Quartz, fused	Insulator	$\sim 10^{-17}$
Ceresin wax	Insulator	$\sim 10^{-17}$
Sulphur	Insulator	$\sim 10^{-15}$
Mica	Insulator	$\sim 10^{-15}$
Paraffin	Insulator	$\sim 10^{-15}$
Rubber, hard	Insulator	$\sim 10^{-15}$
Glass	Insulator	$\sim 10^{-12}$
Bakelite	Insulator	$\sim 10^{-9}$
Distilled water	Insulator	$\sim 10^{-4}$
Seawater	Conductor	~4
Tellurium	Conductor	$\sim 5 \times 10^{2}$
Carbon	Conductor	$\sim 3 \times 10^{4}$
Graphite	Conductor	$\sim 10^{5}$
Cast iron	Conductor	$\sim 10^{6}$
Mercury	Conductor	10^{6}
Nichrome	Conductor	10^{6}
Constantan	Conductor	2×10^{6}
Silicon steel	Conductor	2×10^{6}
German silver	Conductor	3×10^{6}
Lead	Conductor	5×10^{6}
Tin	Conductor	9×10^{6}
Phosphor bronze	Conductor	10^{7}
Brass	Conductor	1.1×10^{7}
Zinc	Conductor	$1.7\ 10^{7}$
Tungsten	Conductor	1.8×10^{7}
Duralumin	Conductor	3×10^{7}
Aluminum, hard-drawn	Conductor	3.5×10^{7}
Gold	Conductor	4.1×10^{7}
Copper	Conductor	5.7×10^{7}
Silver	Conductor	6.1×10^{7}
Nb, (Al-Ge)	Superconductor	$\sim \infty$

(b) Permittivity

Medium	Relative Permittivity ε_r
Vacuum	1
Air (atmospheric pressure)	1.0006
Styrofoam	1.03
Paraffin	2.1
Plywood	2.1
Polystyrene	2.7
Amber	3.0
Rubber	3
Plexiglass	3.4
Dry sandy soil	3.4
Nylon (solid)	3.8
Sulphur	4
Quartz	5
Bakelite	5
Formica	6
Lead glass	6
Mica	6
Marble	8
Flint glass	10
Ammonia (liquid)	22
Glycerin	50
Water (distilled)	81
Rutile TiO_2)	89-173
Barium titanate ($BaTiO_3$)	1,200
Barium strontium titanate[1]	10,000
Barium titanate zirconate[2]	13,000
Barium titanate stannate[3]	20,000

[1] ($2BaTiO_3 : 1SrTiO_3$)
[2] ($4BaTiO_3 : 1BaZrO_3$)
[3] ($9BaTiO_3 : 1BaSnO_3$)

(c) Permeability

Substance	Group Type	Relative Permeability μ_r
Bismuth	Diamagnetic	0.99983
Silver	Diamagnetic	0.99998
Lead	Diamagnetic	0.999983
Copper	Diamagnetic	0.999991
Water	Diamagnetic	0.999991
Vacuum	Nonmagnetic	1
Air	Paramagnetic	1.0000004
Aluminum	Paramagnetic	1.00002
Palladium	Paramagnetic	1.0008
2-81 Permalloy powder[a]	Ferromagnetic	130
Cobalt	Ferromagnetic	250
Nickel	Ferromagnetic	600
Ferroxcube 3[b]	Ferromagnetic	1,500
Mild steel (0.2 C)	Ferromagnetic	2,000
Iron (0.2 impurity)	Ferromagnetic	5,000
Silicon iron (4 Si)	Ferromagnetic	7,000
78 Permalloy (78.5 Ni)	Ferromagnetic	100,000
Mumetal (75 Ni, 5 Cu, 2 Cr)	Ferromagnetic	100,000
Purified iron (0.05 impur.)	Ferromagnetic	200,000
Supermalloy (5 Mo, 79 Ni)	Ferromagnetic	1,000,000

[a] (2 Mo, 81 Ni)
[b] (Mn-Zn-ferrite powder)

Figure 2.2/ Tables of Properties for Some Common Materials

2) The target must have at least one of the three parameters different from the surrounding medium by about 50% or more. Usually, a factor of 2 is required.

2.3/ Transmitted Power Level

The transmitted power level determines the capacity required by the transmitter of the radar and to a large extent the cost of the system. The transmitter generates the signal to be propagated and normally this signal is of the order of hundreds, thousands or millions of watts. The determining factor of this power level is the range required to reach the target. Unfortunately, there is a 1/R power loss relation due to spreading of the wave as it travels toward the target. Upon reflection from the target, there is a further 1/R power loss as the wave returns to the radar resulting in a two-way loss of 1/R. Thus, if the power required to detect a target at 10 m is 0.5 W, then the power required to detect the same target at 100 m is $(10)^4$* 0.5 W = 5000 W. Clearly, this is the reason that low power radar (about 1 W or less) can be used by police for traffic control where the range is less than 1 km while high power radar (1,000,000 W) is required for airport radar where the range is much further.

2.4/ Antennas

The role of the antenna for single antenna systems is simply to guide most of the transmitted power in a certain preferred direction and accept reflected power from that same direction. Sometimes this is accomplished by using a pencil-beam antenna, as shown in Figure 2.3, which concentrates the power in a small cross-sectional area. Weather radar usually uses this type of antenna. Search radar, used at airports, normally uses a fan-beam antenna, shown in Figure 2.4, which provides accurate azimuth determination over a large range of altitudes. Height finder radar uses the same type of antenna but rotated 90 degrees to give height of the aircraft. Needless to say, there are a large number of different antennas used for different purposes.

The antenna is normally an expensive item in the radar system. Usually, there is great reluctance to suggestions of changing the antenna since it is almost as cheap to built an entirely new radar.

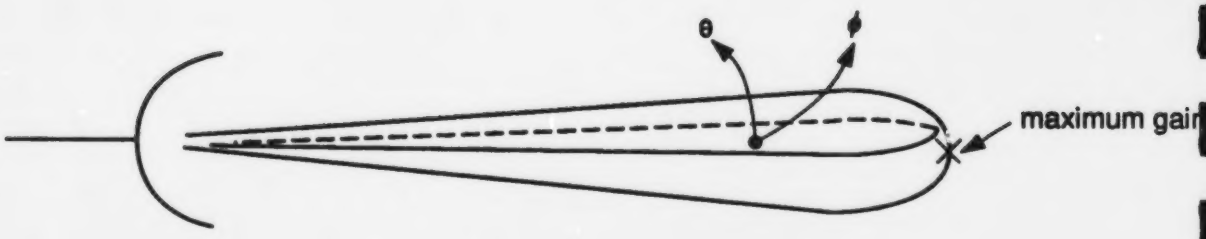
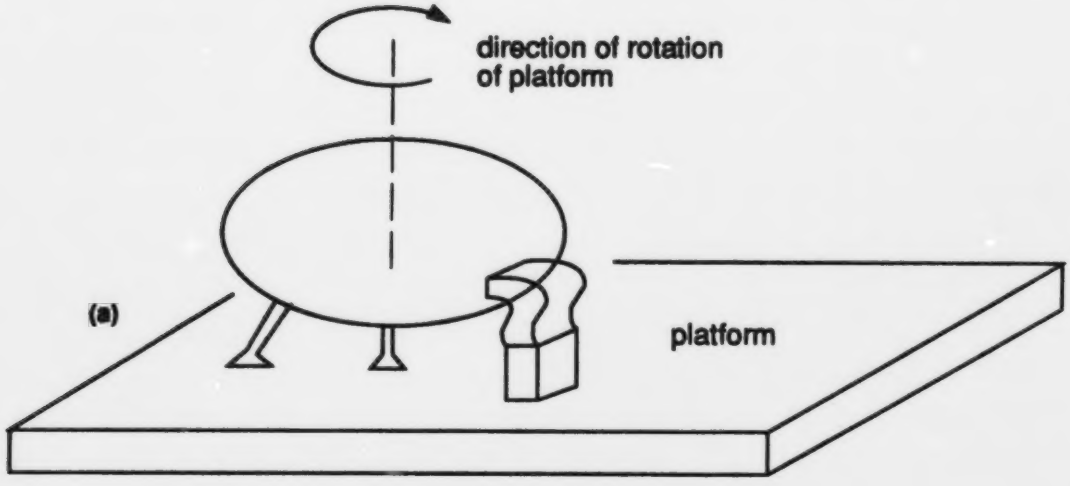


Figure 2.3/ Antenna pattern for a pencil-beam antenna



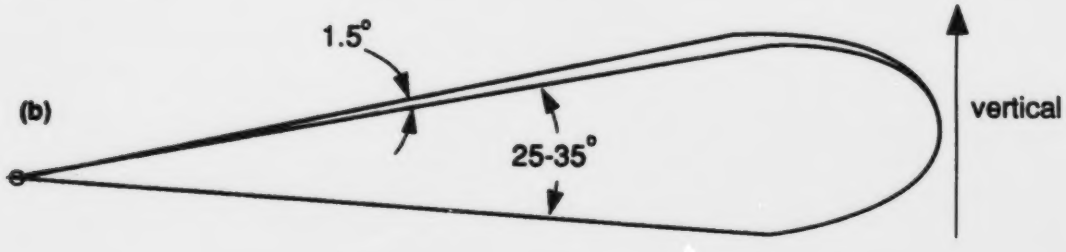


Figure 2.4/ a) Platform assembly for a radar antenna

b) Fan-beam antenna pattern

2.5/ Receiver System

The receiver system is an extremely important part of the radar since it is here that the returned signals are processed in order to detect the targets. Usually, there are amplifiers and filters which condition the signal in order that other processes such as the presence of a target can be detected or the motion of a target can be detected. Almost always these outputs will be fed to a computer for further processing using sweep-to-sweep analysis or spectral analysis.

2.6/ Pulsed and Continuous Transmission

All radars transmit one of two different formats for the signal, either pulsed or continuous. A brief explanation of these is now given.

A. Pulsed Radar

Pulsed radar, such as that used at airports and weather stations, is used mainly for locating and detecting the presence of a target. The technique, well described in the literature [5], employs a signal which is simply a short duration burst of electromagnetic energy usually at a constant frequency, as illustrated in Figure 2.5a. When transmitted in air, the pulse propagates at the velocity of light which is approximately 300 metres per microsecond (1 microsecond = 10^{-6} seconds). If any obstruction (usually called a target) is encountered, then a reflection is produced which is related to the difference in electrical properties between air and the target. Since there may be many targets at different ranges, there are normally many different reflections all separated in time as illustrated in Figure 2.5b.

The strength of each reflection depends on the material of the target, the size of the target and the range from transmitter to target. If there are many targets, then there are many reflections and these reflections may overlap. For a given set of targets with spacing in range at least equal to d, the width of the pulse used must be no more than approximately 2d/c, where c is the velocity of light. Hence, if the spacing is equal to 600 m, the the maximum pulse width which can be employed is 2 μs.

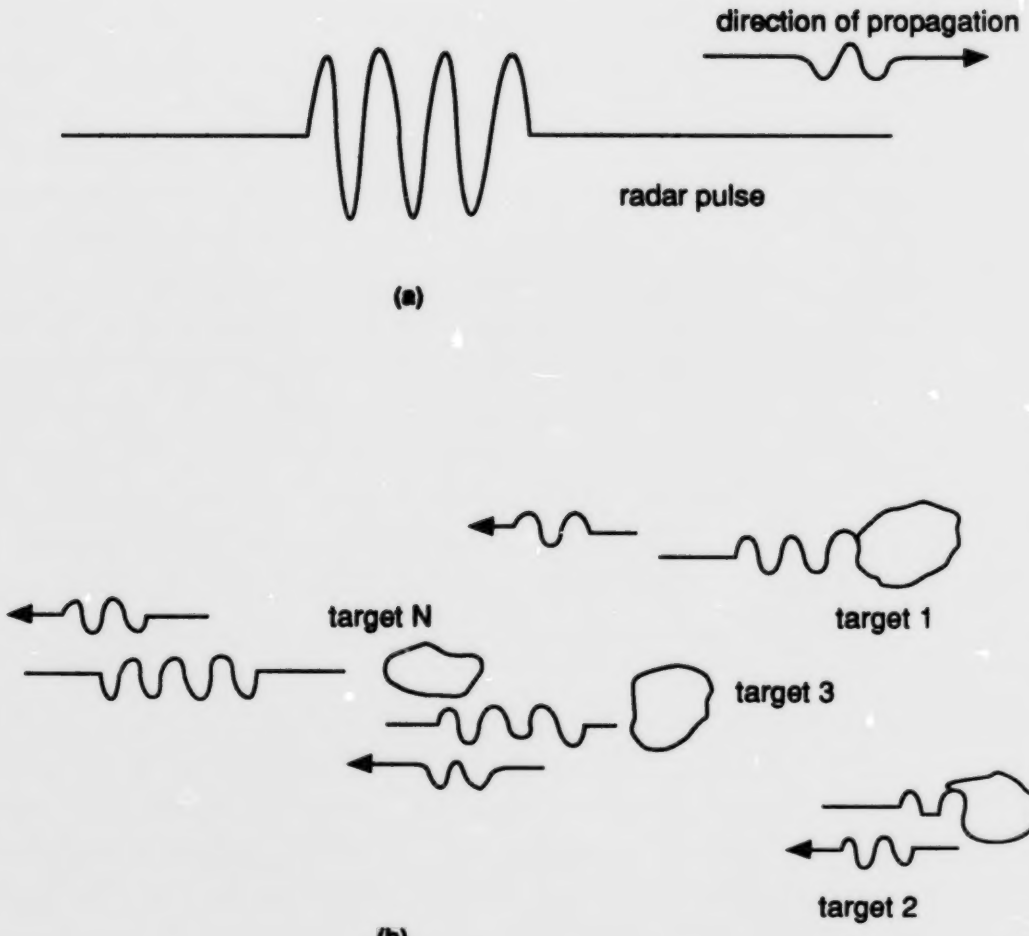


Figure 2.5/ a) Single transmitted radar pulse

b) Returns from N different targets at different points in space

While it is true that pulsed radar is usually used for detection of the presence of a target, it can also be used to detect motion by employing either the 'pulsed Doppler radar' or the moving target indicator configurations. The former is a compromise which offers reduced performance in the location determination of the target while giving some indication of the motion of the target. The latter maintains the good location performance properties of the pulsed radar while giving very limited information on target motion.

B. Impulse Radar

Impulse radar is a special type of radar which has no carrier frequency. There is a wide range of applications [7-13] including detection of faults in bridges [1-4]. The main advantages of this are:

1) additional information can be obtained by eliminating the carrier in that polarity of the reflected signal is preserved in the radar receiver; and
2) small changes with the pulse width can be exploited to give a fine resolution feature not usually found in conventional pulsed radar.

The disadvantages include:

1) the problem of wide bandwidth which leads to an expensive antenna; and
2) very limited range since the normal superheterodyne techniques cannot be used to provide low noise amplification.

However, for the certain well-defined applications such as evaluating bridge decks or detection of buried objects, impulse radar is highly effective.

C. Continuous Transmission Radar

Continuous transmission radar is often referred to as 'continuous wave (CW)' radar and is also well represented in the literature [5]. In this case, the transmitted signal is always on and the reflections from targets are always being received. Thus, it is not possible to measure distance to target by using CW radar. The main use of CW radar is in motion detection, such as that used by the police to detect the speed of vehicles for traffic control. When the signal encounters a moving vehicle, the frequency of the reflected signal is either increased or decreased, depending on whether the target is approaching or regressing according to the relation

$$f_d = 2 f_0 v / c \qquad (2.1)$$

where: f_d = Doppler frequency shift due to target motion
f_0 = frequency of the radar
v = velocity of the target
c = velocity of light

Normally, CW radar cannot be used to determine the location of a target since the time relation between the transmitted signal and the reflected signal cannot be measured. However, if the frequency of the transmitted signal is changed smoothly with time over a certain period, then a correlation technique can be used to provide location as well as velocity. The system is then called FM radar and enjoys limited success in certain well defined applications.

2.7/ Applications

The applications for radar are almost endless. In the Ministry context, however, there is a more limited range which are discussed in the next section.

3/ General Applications of Radar for the Ministry

3.1/ Introduction

The use of radar in the areas of air traffic control, weather monitoring and ship navigation are all well documented in the literature for the past thirty years. Radar provides the user with a tool that can be exploited in the areas of remote sensing and non-destructive testing.

The results of a computer literature search have indicated that the possibility of using radar for remote sensing applications in the areas of highway design, construction and maintenance is quite promising. The four major subject areas that have been identified for further investigation are:

1. Site Conditions
2. Pre-engineering, Quality Assurance and Maintenance
3. Weather Monitoring and Road Surface Conditions
4. Traffic Characteristics

We now provide an overview of the results of the investigation as related to each of these areas.

3.2/ Site Conditions

The use of radar in geophysical ground mapping has received considerable attention in the literature from both theoretical [14-15] and practical standpoints [16-36] and may well have benefits in the area of highway construction. In addition to the monostatic radar technique used by the Ministry, there are three other fundamentally different methods which have evolved and these are now described briefly [17].

The first method, called Melos Method, relies on measuring the components of electric and magnetic fields on the surface of the ground. The measurements are used to calculate the conductivities of ground layers. As the frequency is changed, the thickness of different layers is determined according to skin depth. Normally, frequencies in the range of 1 to 100 kHz are employed.

The second method, called interference measurement, is based on the use of a transmitting antenna using a pair of orthogonal dipoles placed near the ground surface [17-18]. Two types of waves are generated which are received by another pair of orthogonally placed dipoles. An interference pattern is produced and the ground layers can be inferred. Usually, the frequencies used lie in the band from 1 to 50 MHz.

The third method, called bistatic radar method, employs two separate antennas, one for transmitting and the other for receiving [19-28]. There are may different applications reported in the literature including the measurement of glacier thickness [19], exploration of coal seams [20], the detection of geological layers [21-23], permafrost detection [24-26], moisture content of soil [27] and the identification of lake bottoms [28]. Most of the radars used in these applications use frequencies from 30 to 1000 MHz and short pulse lengths (of the order of 1 to 50 ns).

Other methods of geological use of radar include scatterometer, which is useful in determining the moisture content of soil [29-33] and synthetic aperture radar (SAR) which is often carried by aircraft or satellite [34-36]. In one instance, ancient dried riverbeds in Egypt were detected using this method [36].

A problem with these systems is the antennas tend to be sizable as compared to the conventional low power microwave radars.

For most of these above-mentioned systems, the range of detection extends over many tens or hundreds of metres whereas the present requirement would probably find more use in the range from 1 to 20 m. This could be accomplished by simply employing a shorter duration pulse width at a higher repetition rate. In addition, it is possible that higher frequencies could be employed which would reduce the size of the antenna(s).

Some possible applications include:

a) The measurement of depth to bedrock;
b) The measurement of thickness of layers of sand, soil, gravel, etc;
c) The measurement of thickness of road gravel;
d) The detection of underground rivers;
e) The detection of water saturated soil.

Other forms of radar have also seen used for evaluation of ground conditions. A microwave frequency radar operating at 4.5 GHz using FM-CW mode has been used to determine vegetation covers over ground and soil moisture. However, no indication was given of the ability to determine layers of soil.

3.3/ Pre-engineering, Quality Assurance and Maintenance

The literature search provided no papers in the areas of pre-engineering, quality assurance or maintenance in the area of highway construction. However, it is not difficult to suggest some possible applications. These include:

a) Measurement of concrete cover over reinforcement, concrete thickness and asphalt thickness.
b) Detection of voids and deteriorated joints or frost heaves.
c) Detection of steel beams or reinforcement encased in concrete or other construction material.
d) Measurement of concrete thickness in retaining walls or sidewalks or sidewalls of bridges.
e) Measurement of faults in columns, beams and piers in buildings and other structures.
f) Location of drainpipes.
g) Tunnel wall thickness evaluation.

3.4/ Weather Monitoring

It is assumed in this study that the requirement for weather monitoring is limited to accurate information of conditions at specific sites of perhaps a few kilometres in range or less. For example, this could include the intersection of major highways such as highways 400 and 401, or perhaps sections with heavy usage such as the QEW. Such information is not usually available from satellite sources or from large radar installations, such as at Pearson International Airport. Data from all sources can then be combined with more specific information to give an overall picture.

Weather monitoring, in general, includes the measurement of all parameters which indicate atmospheric conditions. Amongst the parameters are, for example: temperature, wind speed and direction, atmospheric pressure, dust content, humidity, fog and precipitation. It is

important to note that any selection of sensors must operate both during the daytime and at night; thus, methods based on the use of variations of light intensity may be difficult to apply.

Of the above-mentioned parameters, radar has the ability to measure precipitation. The precipitation may be in several different forms including rain, hail (or frozen rain pellets) and snow. If precipitation is present, radar may also be used to determine wind speed and direction.

There are five different methods employed to detect precipitation, namely [37]: Attenuation, Doppler, Polarization, Bistatic and Two-Frequency. Each of these methods is now briefly described.

A. Attenuation Method

This method is particularly effective for measuring rain, less effective for measuring hail and of no use for measuring snow [37]. It is well known that water is a polar molecule which absorbs microwave energy in a frequency band centred around 22.2 GHz. At 33 GHz, it has been found that the rainrate can be determined almost independent of drop size distribution. Consequently, it is possible to use this property to detect the presence of rain by simply transmitting a signal with this frequency and measuring the loss. Experimental data indicates that the loss lies between 0.2 R and 0.27 R dB/km where R is the rainrate in mm/h.

Figure 3.1 illustrates a simple monostatic system comprising a radar and a reflector. Normally, the signal propagates from the antenna to the reflector and back with a certain propagation loss. When rain is present, the loss is increased by the amount of absorption of the rain. Since the absorption can be calibrated as a function of the amount of rain in the path, it is possible to deduce the rainfall rate. A suitable distance between the transmitter and reflector is 200 to 400 m. Using the latter figure, the total range is 800 m and with a rainrate of 20 mm/h, the added attenuation due to rain is 4 dB (assuming 0.25 R dB/km attenuation rate).

The system can be implemented using either pulse or CW radar. With pulse radar, some information on rainfall at different ranges is possible (specially if multiple reflectors are employed). However, CW radar is less expensive and simpler to implement.

Installation would be quite simple since the radar could be mounted on an overhead sign above a highway and use any available metal reflector. Some care would be required to avoid reflections from traffic on the highway.

B. Doppler Method

The Doppler method relies on the use of CW radar to measure the variation in velocity of falling particles to distinguish between rain, hail and snow [38]. It has been shown that these different velocities are in fact significantly different and lead to distinguishable boundaries. It is also possible to gain some information as to reflectivity by the return signal strength. Unfortunately, the method does not seen to have been fully investigated.

One possible implementation is shown in Figure 3.2. The antenna is pointed into the air at a certain angle to ensure that no reflections occur from any other objects. An effective feature would be to provide a rotating platform with a wind vane to ensure that the radar always faces directly into the falling precipitation.

This could also be located on any available overhead sign above a highway. Clearly, there would be no interference from traffic due to the angle of the antenna.

C. Polarization Method

The polarization method is particularly effective for detecting rain or hail [39-46]. The technique is based on the observation that raindrops are non-spherical in shape and usually fall with a high degree of mutual orientation, as illustrated in Figure 3.3. Larger sized drops are uniformly more deformed than the smaller and have high degrees of orientation of their symmetry axes.

Assume that the radar simultaneously transmits a signal which has two polarizations, one with electric field vertical and the other with the electric field horizontal, as shown in Figure 3.3. Since the backscatter of the waves is related to the interaction of the electric field with the raindrop, the amplitude of signal returned to the radar for each polarization is different. This difference can be expressed as a ratio Z_{DR}, where

$$Z_{DR} = 10 \log (Z_H/Z_V) \qquad (3.1)$$

and Z_H = backscatter due to horizontal polarization

Z_V = backscatter due to vertical polarization.

Figure 3.1/ Monostatic radar with reflector

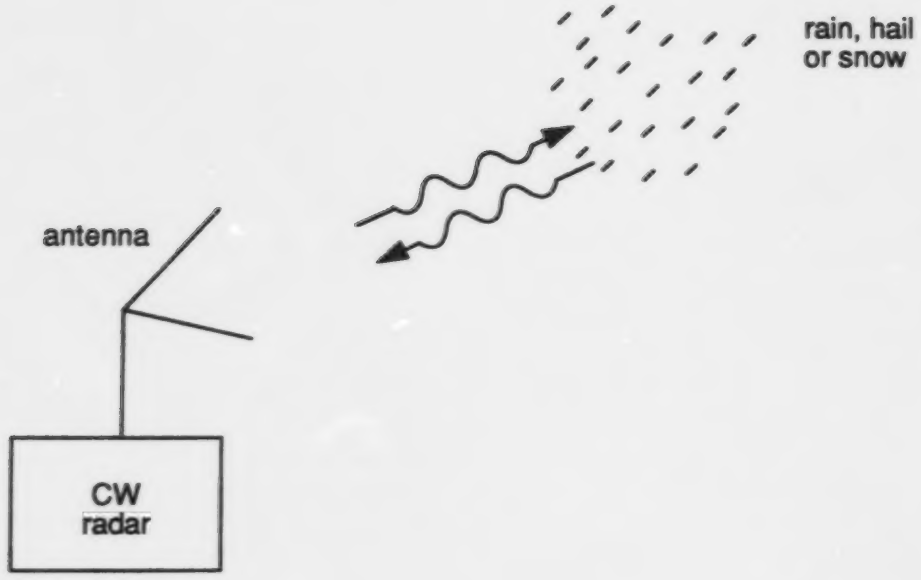


Figure 3.2/ Doppler radar implementation

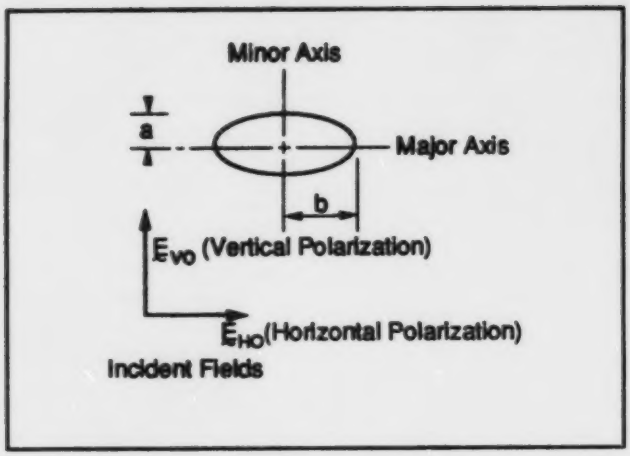


Figure 3.3/ Oblate spherical raindrop and orientations of vertical and horizontal polarization

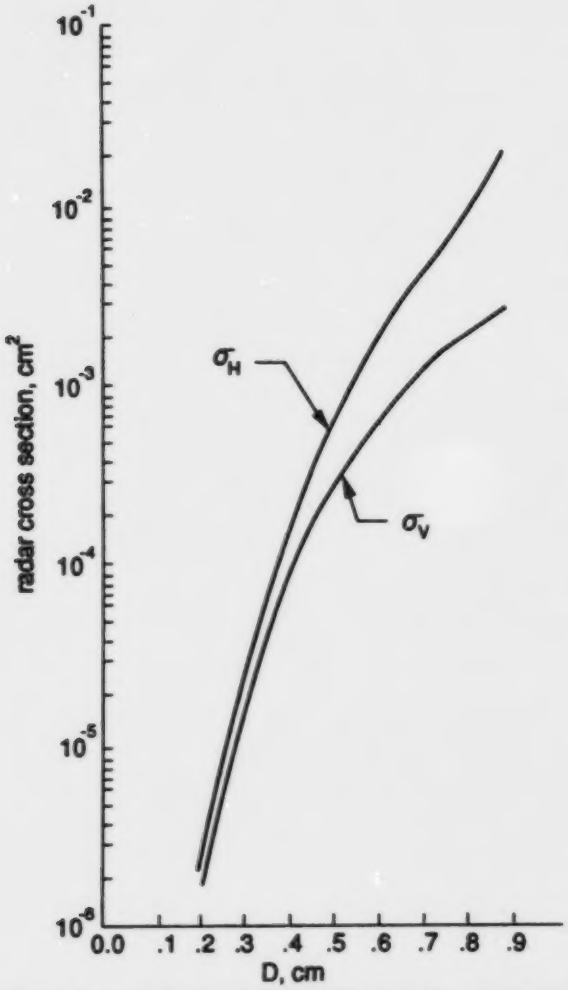


Figure 3.4/ Horizontal and vertical radar cross-sections of oblate spheroids

In order to gain some insight as to the magnitude of Z_{DR}, we note that the horizontal and vertical radar cross-sections of oblate spheroids with diameter D can be determined theoretically, as shown in Figure 3.4. Since these cross-sections are proportional to the backscatter signals, we then obtain a measure of Z_{DR} as a function of median drop diameter, D_0. It is then possible to relate the the rainrate R to the value of Z_H. Thus, use of dual polarization leads to evaluations of both the size of raindrops and the rate of rainfall.

Typical values of Z_{DR} for rain range from 0 to 5 dB and values of Z_H may vary over 60 dB. Experimental verification of the method is provided in the chart of Figure 3.5 where we see that the system compares well with measured rainfall values.

Implementation is somewhat more complex than the two previous methods. Either the radar must have dual polarization with switching or some means of transmitting and receiving dual polarization simultaneously. Another possibility is to use two low cost radars with slightly different frequencies and one antenna rotated 90 degrees to the other. Both pulsed and CW radar are suitable for the application.

D. Bistatic Method

This method is effective for rain, hail and snow [47-49]. Basically, the bistatic radar relies on the use of two different antennas which are be spatially separated, as shown in Figure 3.6. The signal is transmitted by the first antenna in a certain direction so as to be scattered from the target and be received by the second antenna. Thus, the method can be thought of as relying on forward scatter.

There are some advantages and disadvantages of the system. The main advantage lies in the freedom of choice in locating the second or receiving antenna since it need not be at the same location as the transmitting antenna. Further, the method can be extended by using more than one receiving antenna thus giving coverage in several different locations without having to use multiple transmitters. The main weaknesses of the system include selecting the optimum locations for receiving antennas and the added cost of using one or more separate receiving antennas. Dual polarization can be combined with the bistatic technique to give the advantages of both systems [50].

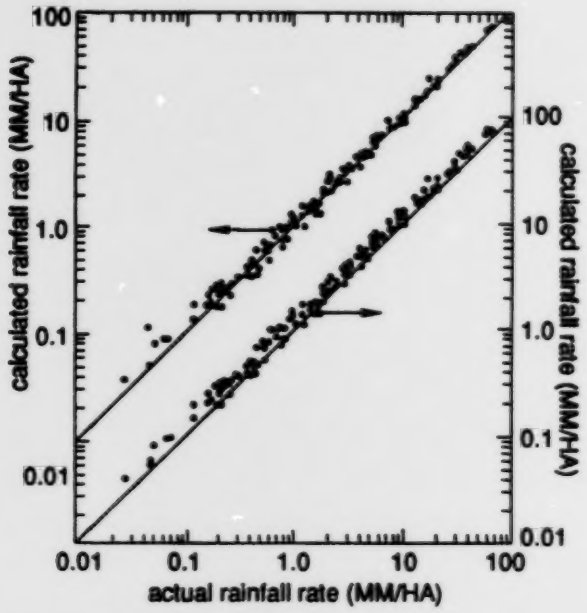


Figure 3.5/ Comparison of actual and computed rainrates

Lower curve assumes exponential size distribution of raindrops, upper curve assumes gamma distribution.

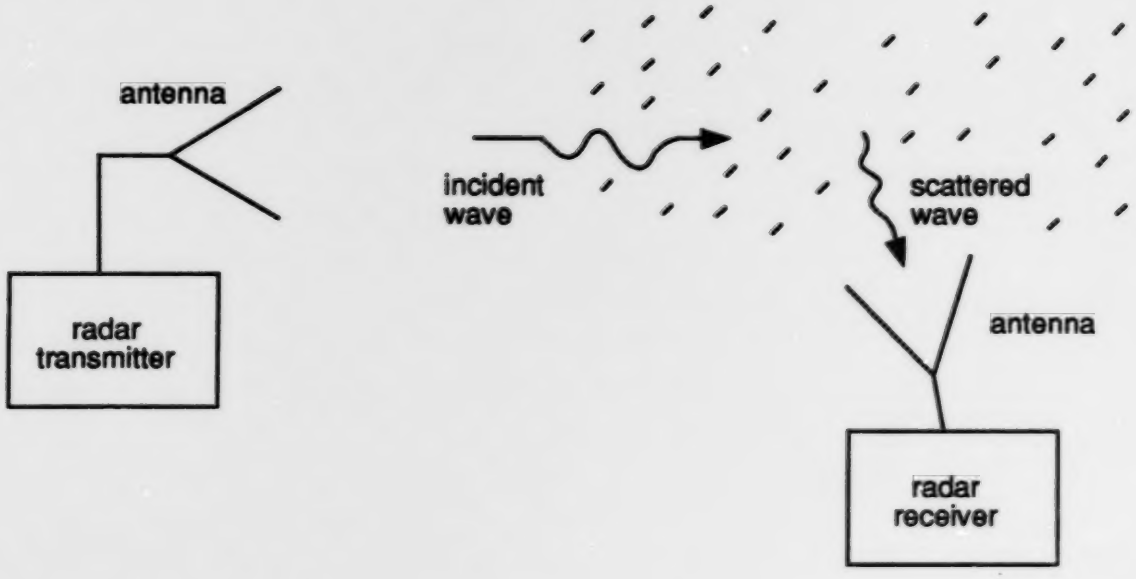


Figure 3.6/ Bistatic radar

A comparison of calculated results has been presented for transmitted frequencies of 3 GHz and 33 GHz assuming a CW bistatic radar. The higher frequency gives some advantages at lower rainfall rates since the wavelength (approximately 9 mm) is closer to the diameter of the average raindrop. Implementing this system could be as simple as locating the transmitting antenna on an overhead sign. Then, the receiving antennas would be located on other overhead signs.

E. Two-Frequency Method

This method, sometimes called multiparameter radar, is effective in measuring rain, hail and snow [51-54]. The main advantage is that the system gives the reflection information at two different frequencies. Since rain is frequency sensitive, it is easily detected. When combined with one of the other methods (such as the Doppler method), the system is effective in detecting hail and snow.

The main problem of the method is the added complexity. Two complete transmitters and receivers are required, which adds greatly to the cost.

3.5/ Road Surface Conditions

The literature search provided no references in this area. However, it is possible to give some general indication of the possible effectiveness of radar in monitoring road surface conditions. Assuming that the conditions to be monitored are water, ice and snow, the property which distinguishes these materials is the dielectric constant. Typical values are:

- distilled water: about 78 at frequencies below 3 GHz dropping to 34 at 25 GHz;
- ice (from distilled water): 3.4 at 100 MHz dropping to 3.2 at 3 GHz;
- snow (freshly fallen): 1.2 at frequencies from 100 MHz to 3 GHz;
- hard-packed snow followed by light rain: 1.5 at 3 GHz.

It is important to note that with any degree of salt on the road, these figures may change significantly.

One method of monitoring the highway surface is to hang a radar from an overhead sign pointing downward at the surface as illustrated in Figure 3.7. Since the dielectric constant of asphalt is known to change depending on the mix, it would be preferable to use concrete as the roadway surface. The reflection of the surface would always be monitored and as the condi-

tions changed the reflection would change accordingly. For instance, we calculate the reflection for the following four conditions assuming concrete (dielectric constant 6) roadway a radar frequency of 3 GHz:

a) bare concrete, reflection coefficient = -0.42.
b) 5 mm water over concrete, reflection coefficient = -0.8
c) 50 mm fresh snow over concrete, reflection coefficient = -0.05
d) 50 mm hard-packed snow followed by rain, reflection coefficient = -0.10.

This indicates that there is a possibility of detecting various surface conditions by using a radar signal. Since distance measurement is not required, either pulse or CW radar is suitable for the application. An obvious problem of reflection from vehicles on the highway can be resolved by noting the dramatic change in signal level which would take place when the signal is reflected by a metal surface at elevated height.

3.6/ Traffic Characteristics

The widest use of radar for determining traffic characteristics lies in the use of CW radar for the measurement of vehicle speed. Two different carrier frequencies are commonly used, namely 10.525 GHz (X-band) and 24.15 GHz (K-band). As well, there are two commonly used modes of operation, the first being with stationary platform, and the second being with moving platform (mounted in a car, for instance). There are many difficulties with the system since the radar does not tell the operator which vehicle is being tracked or the lane in which the vehicle is located. Usually, visual monitoring is necessary and some operator experience is required. However, if properly used, the radar can give very accurate information as to the speed of moving vehicles.

While there are studies available dealing with traffic flow, there seems to be little on the use of unattended radar for monitoring traffic. A major problem specially significant for multi-lane highways is the complexity of the system. It is possible to monitor the lanes using pulsed or CW radar from overhead supports but each lane requires a separate antenna beam or some means of switching. Neither choice is particularly attractive.

4/ Implementation of Techniques

Through discussions with the Ministry personnel, it was determined that certain specific applications related to the findings of Section 3 may be of interest. In this Section, we describe these applications and examine methods of implementation which could be applied. In addition, we provide an estimate of the probable results and the likelihood of the method having success from a technical stand-point.

4.1/ Geophysical Site Conditions

A. Objective

An area of interest is the evaluation of site conditions where glacial till exists over bedrock. It was noted that previous studies using seismic methods and electrical resistivity measurements have been unsuccessful. Currently, this type of site is evaluated by portable drilling. Any other method of evaluation must compare economically with the drilling technique.

It was noted that the typical site is characterized by:

- glacial till containing soil and a mix of boulders usually ranging in diameter from 0.2 m to 1 m with some as large as 10 m.
- A plot of the bedrock surface layer would be highly useful. It was noted that this layer is typically between 0 and 100 m below the surface.
- Bedrock is usually uniform in composition with possible joints and fissures.

B. Proposed Method

The application of radar to detecting the depth of glacial till over bedrock is similar to the more conventional problem of detecting a stationary target in heavy ground clutter. In both cases, there is a major difficulty due to reflections from unwanted targets, in this case the inhomogeneities of the glacial till.

There are two different types of radar which could be used in this application. The first is the impulse type of radar, currently being used for the evaluation of bridge decks and the second is the pulsed carrier type of radar which is normally used for detection the range of targets. The former would be useful where the depth of glacial till is less than approximately 1 to 2 m although a more powerful impulse radar could penetrate further. This depends strongly on the composition of the glacial till. The latter would be capable of penetrating several tens of

metres. On the other hand, the impulse radar signal is usually easier to interpret than the pulsed carrier signal since the phase information is preserved.

C. Method of Operation

Assume that the site to be tested, as illustrated in Figure 4.1, consists of bedrock which forms a reflecting plane over the area of several beamwidths of the antenna (discussed later in detail) and dry glacial till containing a mix of soil and boulders of differing sizes.

The reflections from boulders in the glacial till can be divided into three different classifications:

a) Average diameter of the boulders is much less than the wavelength of the radar (approx. 20 to 50 cm). This region is called the Rayleigh region and is characterised by the radar signal essentially passing around the boulders.

b) Average diameter of the boulders is approximately equal to the wavelength of the radar. In this case (called the Mie region), there would be a strong reflection if the radar had only a single frequency component. However, since the radar is broadband, the reflection would be distorted due to the frequency selectivity of the interaction.

c) Average diameter of the boulders is far greater than the wavelength of the radar signal. This is called the optical region. In this case, the radar signal tends to penetrate the boulder and pass through as if it were a layer. Thus, some measure of the diameter of the boulder is possible.

The only other problem of the glacial till is the presence of water. Normally, water will produce a strong reflection. In addition, water mixed with many types of salt is lossy. Thus, propagation is difficult.

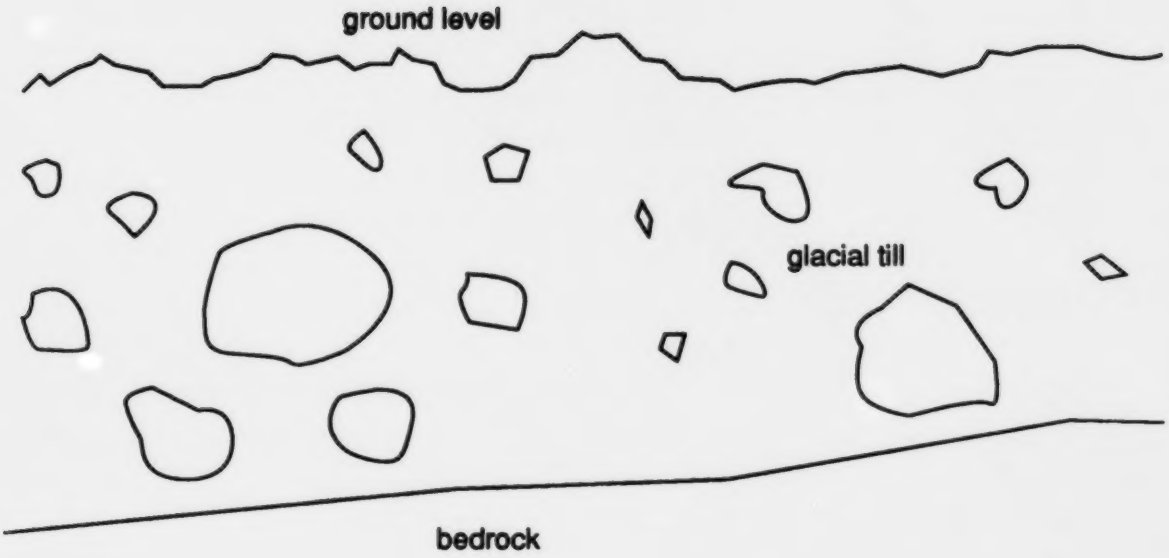


Figure 4.1/ Test site with glacial till above bedrock

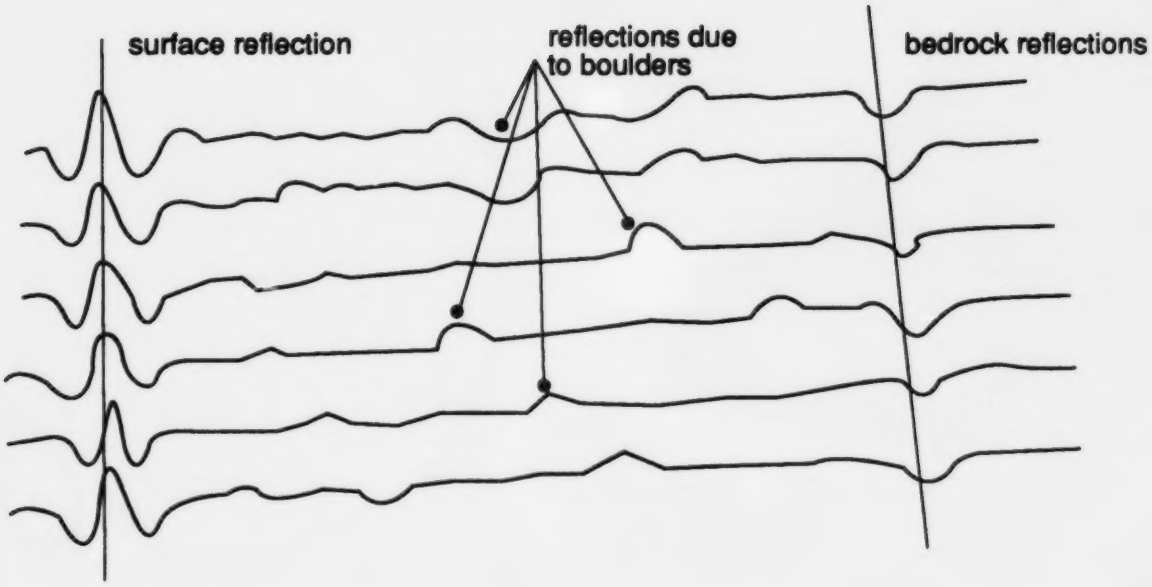


Figure 4.2/ Waveforms from glacial till above bedrock

D. Testing Procedure

Data Collection: Using the Ministry impulse radar, perform the following steps:

1) Mount the radar on front of the van or an appropriate cart and connect the radar outputs and the distance measurements of a fifth wheel to a tape recorder.

   Note that in this case it is important to take measurements more often than in the case of evaluating bridge decks since the motion of the antenna may be used to resolve reflections from boulders. Thus, it is important to record the one, ten, and hundred centimetre distance measurements.

2) Slowly move in along a line in the same manner used to record bridge decks. Repeat the procedure spacing the lines by about 2 m to cover the area as fully as possible.

3) Once the data are recorded, process using the strategy described next.

Processing Strategy: The processing strategy is based on the correlation of reflections of the traces from a bedrock level which changes slowly in depth with respect to the radar antenna motion. From Figure 4.2, we see that the reflections due to boulders of different sizes produces random fluctuations in the waveforms which are not correlated whereas the bedrock level fluctuations are highly correlated. Once the true bedrock level is determined, it might be possible to identify boulders of different sizes and their locations.

E. Probability of Success

The probability of success in this application lies mainly in the characteristics of the site being evaluated. For the case of dry glacial till and bedrock of considerably different electrical characteristics, there is a good chance of success. For the case of moist or wet glacial till over any kind of bedrock, the success is liable to be limited.

Since geological surveys are currently being performed in a wide range of other applications, it appears quite likely that the present application should be further investigated from a technical stand-point. With the present equipment, an ideal test site would be one where the glacial till is no more than 1 to 2 m in depth.

4.2/ Pre-engineering, Quality Assurance and Maintenance

A number of different applications were identified in this category. These are grouped in order to show commonality of the method of implementation.

4.2.1/ Pre-engineering Surveys

A. Objective

To precisely measure the thickness of asphalt. This could be useful in evaluating the amount of asphalt involved in full-depth removal where there may be major variations in depth, or the amount of asphalt already in-place to be re-used.

B. Proposed Method

Measurement of asphalt thickness is already a reality. It is important only that the mix of asphalt be known in order to obtain precise indications of average thickness and consequently amount of asphalt in place.

C. Method of Operation

At present, the DART is fully capable of measuring asphalt thickness. If improved precision of the measurement is required, then additional computer averaging of the waveforms can be performed.

D. Testing Procedure

The method has already been tested on several asphalt covered bridge decks and found to be quite accurate.

E. Probability of Success

Since the method has already been implemented in the detection of faults in bridge decks, the probability of success in very high. Of considerable interest is the determination of just how precise the measurement can be performed by using additional computer averaging of the waveforms.

4.2.2/ Quality Assurance

Three distinct areas were identified in Quality Assurance; namely, End Result Evaluation, Compaction of Asphalt, and Profile of Granular Material. Each of these is now considered in turn.

4.2.2.1/ End Result Evaluation

A. Objective

To evaluate the end-result specification such as asphalt thickness, concrete thickness and cover over reinforcement.

B. Proposed Method

Asphalt Thickness: The measurement of asphalt thickness can be accomplished using the same method employed by DART. This has already been fully discussed in Section 4.2.1.

Concrete Thickness: The measurement of concrete thickness is possible using the currently implemented technique in the DART provided that the reinforcement does not cause too high a reflection. Multiple layers of reinforcement could also be detected in some instances where the layers are spaced by at least 50 mm.

Cover Over Reinforcement: The location and cover of reinforcing has already been demonstrated in principle by the results of the DART but not fully investigated. For concrete over rebars, the concrete and reinforcing produce solid reflections. Since the dielectric constant of the concrete can be measured from the surface reflection, depth of reinforcing should be easily measurable.

C. Method of Operation

For all three applications, the method would be essentially identical with the currently used DART system. However, the different peaks of the waveforms would require more detailed evaluation with the possibility of waveform averaging.

D. Testing Procedure

The testing procedure would follow that currently used with DART. However, in order to evaluate the advantages of waveform averaging, it would be interesting to determine the effects of vehicle speed. This could be done by simply driving over a selected area a slow speed

resulting in a large number of waveforms per metre traveled. Then, the computer could be used to 'thin' the selection by taking every trace, every second trace, every third trace, etc. to determine the degradation.

E. Probability of Success

The probability of success in measuring the asphalt thickness is very high since the method is essentially in use in DART.

The probability of success in measuring concrete thickness depends on the level of interference due to the reinforcement. It appears quite likely that the measurement can be accomplished but further research is required.

The probability of measuring the cover over the top layer of reinforcement appears very encouraging since this detections is already being used in DART. Detection of other layers of reinforcement is also quite probable if the layers are separated by 50 mm.

4.2.2.2/ Compaction of Asphalt

A. Objective

The objective here is to measure the compaction of placed asphalt to ensure that uniformity has been achieved.

B. Proposed Method

Compaction can be measured by noting the surface reflection as the vehicle is being moved along the roadway. The surface reflection is related to the density of the asphalt. Thus, if there is an area of lower density asphalt, the surface reflection will be reduced. The relation is nonlinear and would require a calculation in order to determine the variation.

C. Method of Operation

The method of operation would be the same as now being used with DART.

D. Testing Procedure

The data would be collected in the same way as in the DART.

E. Probability of Success

The probability of success in this case is quite high. However, a preliminary study would be required in order to determine in a practical way the relation between asphalt density and dielectric constant. This could be done by simply comparing the reflection from several different samples of asphalt rolled to produce different densities.

4.2.2.3/ Profile Granular Material

A. Objective

The objective here is to provide an indication of the thickness of granular material placed over a prepared bed.

B. Proposed Method

Profile of granular material is possible provided that the material on which the granular material rests has electrical properties which are significantly different. For example, the measurement of thickness of a layer of sandy gravel over sandy soil may not be possible.

A simple solution to this problem is to locate small metal reflectors on the ground prior to placing the granular material. These reflectors could be cheap aluminum plates or any type of metal 'confetti' which would provide considerable reflective properties. With a few of these benchmark reflectors, it might be considerably easier to then detect the boundary between granular material and ground.

C. Method of Operation

Again, in this case, the operation would be essentially the same as that used in the DART. However, now, it would be necessary to examine the waveforms at the expected depth of the granular material.

D. Testing Procedure

The method could easily be tested by choosing different types of reflectors to evaluate performance. In addition, it would be important to determine the depth of penetration capable with the existing system.

E. Probability of Success

The probability of success depends considerably on the reflection from the buried reflectors. While this may seem to be straight forward, the method would require an investigation to determine quality of the reflected signal.

4.2.3/ Maintenance

Several possible applications of radar were identified. Again, these are grouped since the method of implementation is nearly the same.

4.2.3.1/ Detection of Deteriorated Joints

A. Objective

Deterioration often occurs at the joints between concrete slabs, as illustrated in Figure 4.3. In this case, the concrete thickness is reduced in the vicinity of the joint.

B. Proposed Method

Using the same technique as in DART, it is proposed that both the top surface reflection and the bottom surface reflection be processed. For slab locations in good condition, the proper thickness will be measured; however, for deterioration, the time between reflections will be reduced.

Of some importance is the fact that reinforcement runs between the concrete slabs, as shown in Figure 4.4. In order to minimize the interaction of the radar signal with these bars, it is suggested that the antenna polarization be rotated 90 degrees to the direction of the bars.

C. Method of Operation

The method of operation is essentially the same as that used for DART.

D. Testing Procedure

Of considerable interest is the comparison of the reflections as the polarization of the antenna is changed from parallel with the rebars to perpendicular to the rebars. A second effect to be evaluated is the interaction between the joint itself and the two polarizations. At present, there is no clear indication of what may result.

E. Probability of Success

It appears quite likely that there will be some success in this area. However, there are some possible problems. Of some concern is the fact that the region containing the deterioration may be filled with gravel, sand, water or air. These factors would influence the measurements obtained. Clearly, an investigation in this area is required.

4.2.3.2/ Detection of Voids or Frost Heaves Under Pavements

A. Objective

In this case, it is required to detect regions filled with air or water which exist under a pavement. The possibility also exists that there could be ice (especially in the case of a frost heave).

B. Proposed Method

The detection of voids under pavement would follow the same general method used in DART. However, in this case, the reflection from the lower side of the pavement would be of interest.

Normally, it is assumed that the pavement rests on road gravel. In this case, the reflection from pavement to gravel would be relatively small. If, on the other hand, the region is filled with water, then detection would be straight forward since the asphalt-water or concrete-water interfaces are highly reflecting.

Discrimination between the pavement and air would also be possible since the reflection changes polarity when traveling from pavement into air. For the case of a void filled with ice, it may not be possible to detect the void since the relative dielectric constant of ice is normally in the range of 3 to 4 and may be indistinguishable from road gravel.

C. Method of Operation

In this case, the method of operation is essentially the same as used in DART. However, the computer would now look for the reflection from the pavement-gravel interface.

D. Testing Procedure

Testing would be essentially the same as for the DART.

E. Probability of Success

The probability of success in this case is very good since the reflections from voids filled with air or water should be quite pronounced. Obviously, there is a problem where reinforcement is present since there will be reflections from any rebars.

4.2.3.3/ Detection of a Washout

A. Objective

In this case, it is required to detect a small gap (washout) or thin layer of wet material under concrete or asphalt.

B. Proposed Method

Detection of a thin gap washout is possible provided that the material in the gap is sufficiently different in electrical properties from that of concrete or asphalt. Water in the gap is ideal since its impedance is far lower than either material. A mixture of sand and air would produce an inconclusive result since the change in impedance is small.

C. Method of Operation

The method of operation here is essentially the same as for DART. However, it may be desirable to average more waveforms in order to improve the accuracy.

D. Testing Procedure

The procedure is similar to that used in DART.

E. Probability of Success

In this case, the success depends largely on the material filling the gap. If the material is water, then the chance of success is good. However, if the material is sand, then the chance is poor. Thus, in general, it appears that detection of thin gaps is not very likely.

4.2.3.4/ Detection of Cracks in Beams, Columns and Piers

A. Objective

The objective is to detect cracks and faults in beams, columns and piers.

B. Proposed Method

In this case, very little is known as to the interaction of a radar signal with any of these structures. It is suggested that some preliminary measurements be taken and evaluated.

C. Method of Operation

In this case, it would be of considerable interest to evaluate some different testing schemes such as changing the polarization, and the angle of incidence. Also, a matching layer could be evaluated to determine whether more of the signal could be coupled into the concrete.

D. Testing Procedure

In this case, some new testing procedures would be required. It is suggested that an experiment be conducted on suitable structures which are scheduled for demolition in order that some relation between waveforms and structure be realized.

E. Probability of Success

Since there is no previous work in the area, the results could range from spectacular to meaningless. This is truly a research topic.

4.3/ Weather Monitoring and Road Surface Conditions

Normally, weather monitoring is obtained from Environment Canada. Thus, forecasting information is available. There are several other functions which could be provided, as now described.

It is, of course, assumed that the equipment is adequately protected against the elements and, in particular, freezing temperatures. Many solid state components which operate satisfactorily at room temperature or in the 0 to 70°C temperature range will either be damaged by low-temperature operation or fail to perform.

4.3.1/ Identification of Icing and Frosting Conditions, and Premature Icing of Bridge Decks

A. Objective

The requirement here is the detection of a thin layer of ice or frost on an asphalt or concrete surface.

B. Proposed Method

The problem is complicated by the fact that the dielectric constant of ice (3.2 to 3.4 in the frequency bands of radar) is not sufficiently different from that of asphalt or concrete to change the reflection significantly.

For asphalt with dielectric constant of about 4, the effective dielectric constant with a thin layer of ice has negligible change. When concrete is considered, the change is of the order of 2 to 3%.

It is also possible to consider the change in reflection when either a metal plate (which may be representative of metal bridge decks) or a perfect microwave absorber is imbedded in the road. For these two cases, the change in effective dielectric constant with a thin layer of ice or frost is still too small to be useful. The problem is due to the fact that the reflection coefficient from air into a thin layer of ice is insufficient to produce a reliably measured reflection. Thus, there is little chance that radar can be used to detect ice by simple normal incidence reflection.

One solution to the problem is to direct the radar signal toward the concrete pavement at an angle of about 68 degrees to the normal, called the Brewster angle, as illustrated in Figure 4.5. Then, the signal will largely be directed into the concrete. With a layer of ice or frost, the critical angle requirement is upset and a significant reflection then takes place. Using a reflector, this signal could be redirected back to the radar.

C. Method of Operation

Since the proposed techniques require no moving vehicle, it is relatively simple to locate the equipment at the desired sites. There would be a need for digital signal processing equipment and a means of communicating the information to the proper authority.

D. Testing Procedure

In this case, testing could be simply accomplished by locating the currently used Ministry radar at an appropriate test site and determining whether the conditions in question could be identified.

E. Probability of Success

Unfortunately, the complexities of the experiment suggest the chance of success is rather low.

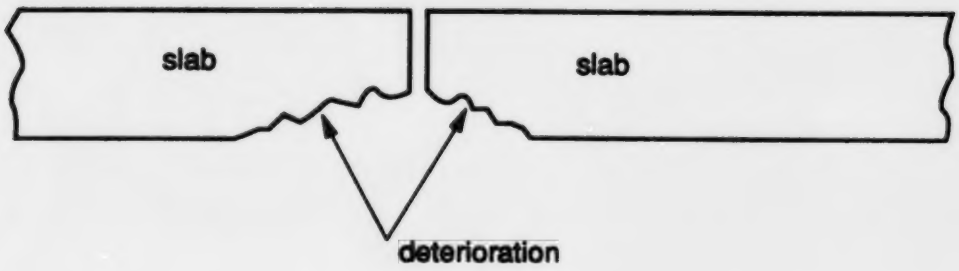


Figure 4.3/ Deterioration at joints

Note the decrease in thickness of the slabs at the fault

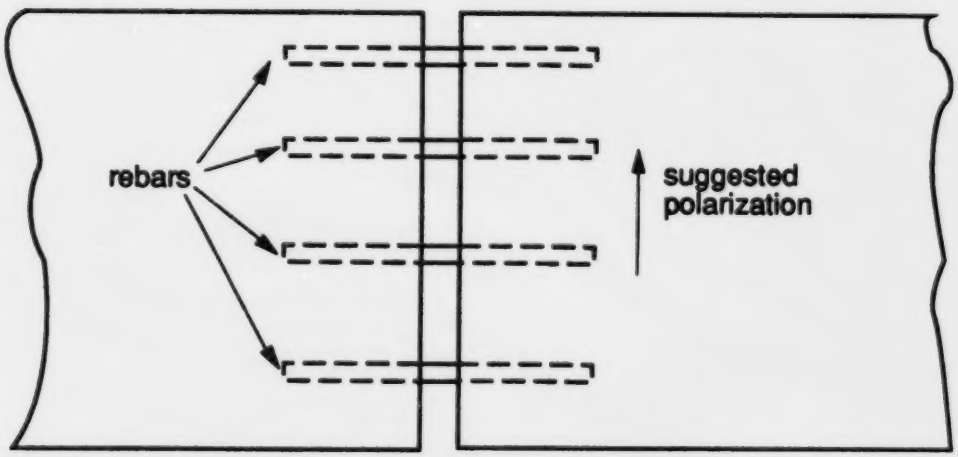


Figure 4.4/ Rebars joining two slabs

Less interaction should be obtained with the polarization as shown.

4.3.2/ Detection of White-out

A. Objective

The objective here is to detect the presence of blowing snow across or along a highway.

B. Proposed Method

Impulse and Pulsed Carrier Radar: Freshly fallen snow has a dielectric constant of approximately 1.2. It appears quite likely that blowing snow would have a dielectric constant somewhat less than this. However, since the spatial extent of blowing snow is usually considerable, it may be possible to produce a meaningful reflection using either impulse or pulsed carrier radar.

The snow cloud would probably be required to fill the antenna beamwidth in order to produce a sizable reflection. This, of course, appears to be exactly the case that is to be detected. In addition, the reflection from blowing snow would be distributed in range which would allow for integration over the path. Of course, there would be some problem in ensuring that the beam did not reflect from the traffic itself. Perhaps the pointing the beam at a small upward angle would provide the necessary solution.

CW Radar: Since the blowing snow has a velocity component, it may be possible to obtain a meaningful measurement with CW radar similar to that used by the police for traffic control. If the reflection were sufficient, then a direct measure of the speed of the blowing snow would be possible.

The only shortcoming of the method is that the spatial location of the blowing snow cannot be determined using CW radar. This problem can be partially solved by combining the features of pulsed carrier radar and CW radar in the pulsed Doppler radar system which can measure both velocity and position. However, the resolution in both range and velocity measurement with this radar is compromised by the combined requirement.

C. Method of Operation

Essentially, the equipment would be located at the side of the highway to be monitored. In addition to the radar, some digital processing equipment would be required and a communications link established to the authorities would be needed.

D. Testing Procedure

Testing of the method could be achieved by using Ministry radar. It would only be necessary to find a field in which blowing snow occurred and then determine the extent of the reflection.

E. Probability of Success

Due to the poor reflective properties of snow, it appears that light blowing snow conditions could not be detected. Hence, the chance of success for this applications is relatively low.

4.3.3/ Identification of Roadbed Conditions in Springtime

A. Objective

The objective in this application is to detect freeze/thaw conditions under pavement where it is assumed that the ground under the pavement may be wet, frozen or dry. In addition, it is well-known that the freeze/thaw conditions of springtime can weaken the roadbed. This may lead to small cracks which could be detected.

B. Proposed Method

Detection of Wet/Frozen/Dry Conditions: Since detection of these conditions has already been discussed in Section 4.2.3.2, no further analysis is presented here. However, we note the following:

1) The detection of wet conditions may be quite simple.
2) Distinguishing between dry and frozen conditions may be somewhat unreliable since the relative dielectric constant may not be sufficiently different.

C. Method of Operation

The method here is essentially the same as for DART.

D. Testing Procedure

Using the DART, it is suggested that the technique be tested by comparing the signals obtained in summer with those obtained in winter for a selected length of highway. In this way, the problem of distinguishing between dry and frozen conditions would be resolved.

E. Probability of Success

The probability of success here depends largely on the results of the testing procedure outlined in Part D. If dry and frozen conditions can be resolved, then the method would have a high probability of success; otherwise, the chance of success is low.

4.3.4/ Identifying Buried Plastic Pipe

A. Objective

The objective is to detect plastic pipe which may be carrying fuel, gas, water or wires.

B. Proposed Method

The main problem in detecting plastic pipe is the fact that plastic normally has a dielectric constant in the range from 2.5 to 5. Consequently, the detection of the plastic itself when surrounded by earth of nearly the same dielectric constant is rather unlikely.

However, if the plastic pipe contains a material with significantly different impedance from ground, such as metal wire or cable or water or air or gas, then the radar signal will penetrate the plastic and reflect from these materials. Hence, detection may become much simpler.

Of considerable significance is the fact that the pipe has a spatial characteristic which can be exploited. Thus, moving the radar antenna could lead to detection of the 'line of the pipe'. This then becomes a problem in image processing.

C. Method of Operation

The method of operation may be similar to DART if the terrain to be examined is relatively flat. However, if the terrain is bumpy or rocky, then individual measurements would be required at gridpoints spaced at approximately 1 to 2 m centres, depending on the estimated depth of the pipe. In any case, the material presented in Section 4.1 dealing with geophysical site conditions would apply.

D. Testing Procedure

Here again, there may well be an interaction between the incident wave and the pipe which depends on polarization. Thus, it would be interesting to investigate these factors using the Ministry DART at an appropriate test site.

E. Probability of Success

In this case, the probability of success depends heavily on the soil in which the pipe is buried, the depth of the buried pipe and the material inside the pipe. Thus, the probability may range from essentially zero to almost unity.

4.4/ Traffic Characteristics

There is considerable interest in identifying methods of remote sensing certain characteristics of traffic flow since on-road sensors are often damaged by the traffic. Further, buried sensors can be used but these weaken the roadway and suffer from broken wires.

There is a problem in locating a radar since some structure may be required. Mounting a radar sensor from an overhead sign could be a problem since the signs are not totally stable. An estimate of the effects of the motion would be required.

4.4.1/ Traffic Counts and Percentage Trucks

A. Objective

A requirement exists in developing an automatic means of obtaining traffic counts and estimating the percentage of trucks. If possible, the method should automatically identify the number of axles and type of truck.

B. Proposed Method

Traffic Counts and Percentage Trucks: The detection of individual vehicles using either an impulse radar or a pulsed carrier radar would be fairly easy provided that the individual lanes could be monitored separately. Trucks and cars could be distinguished on the basis of length. It would also be possible to employ a special antenna system which would allow sampling of the different lanes using only one radar system.

It may also be possible to achieve these goals using CW radar as described in Section 4.4.2.

Number of Axles and Type of Truck: Identifying the type of truck and the number of axles appears to be more difficult. Perhaps the length of the truck would give some indication of number of axles. In addition, it would be possible to distinguish between a flatbed and a conventional transport. However, it is unlikely that a tank truck carrying gasoline would be distinguishable from a conventional transport.

C. Method of Operation

This would require further study relating to the actual conditions on the highway and the problems of providing the necessary support structures for the radar system. In addition, the

method would require the use of digital signal processing equipment and a communications channel to relay the information.

D. Testing Procedure

Some testing of the methods described above could be attempted using the existing Ministry radar. Obviously, it would be useful to start with a relatively light traffic load of identifiable vehicles and proceed to the more congested conditions.

E. Probability of Success

The probability of success in determining traffic counts and percentage trucks is reasonably good. However, there appears to be little chance of achieving success in determining the number of axles or the type of truck.

4.4.2/ Average Speed of Traffic

A. Objective

For this application, it is desired that an estimate of the average speed of traffic be obtained.

B. Proposed Method

For all radar signals, the reflections from cars and trucks should be easily distinguishable from the asphalt surface. Further, with proper Doppler measurement, it would be possible to determine vehicle speed or average speed of traffic.

If only vehicle speed is required, then CW radar similar to that used by the police can be employed. These radar units are fairly low cost (about $1500/unit) and give accurate results.

C. Method of Operation

To monitor several lanes of traffic, a set of CW radars could be mounted over a highway with each radar irradiating one lane. This type of radar could possibly be modified to give traffic counts by measuring the pulse duration of the reflections from vehicles. However, the problem would require some study.

D. Testing Procedure

A simple test could be conducted using the standard police radar. In this case, the radar output from one lane of traffic on a lightly traveled road could be recorded. Every time a Doppler return is obtained, vehicle speed would be measured and the time duration of the reflected

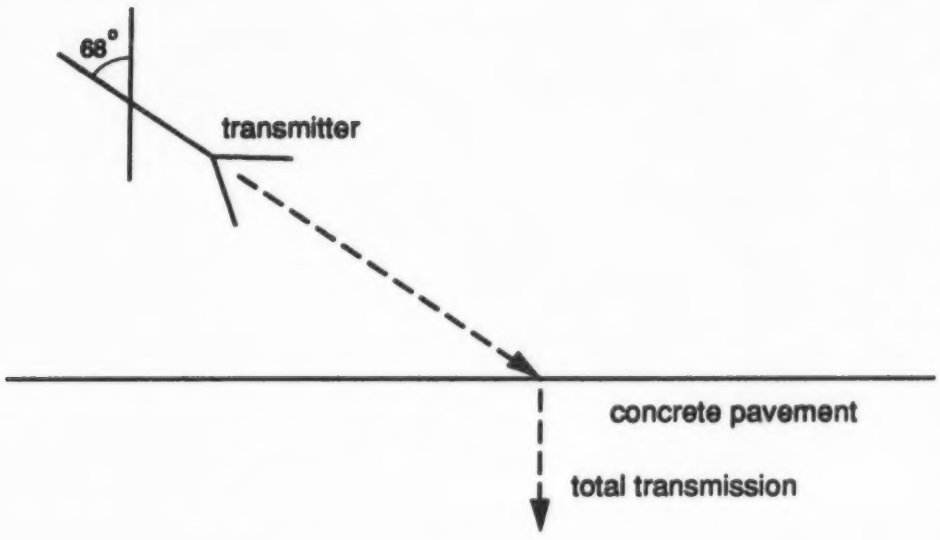
signal would be determined. With these two pieces of information, it would be possible to estimate average vehicle speed and perhaps vehicle counts and length of different vehicles.

E. Probability of Success

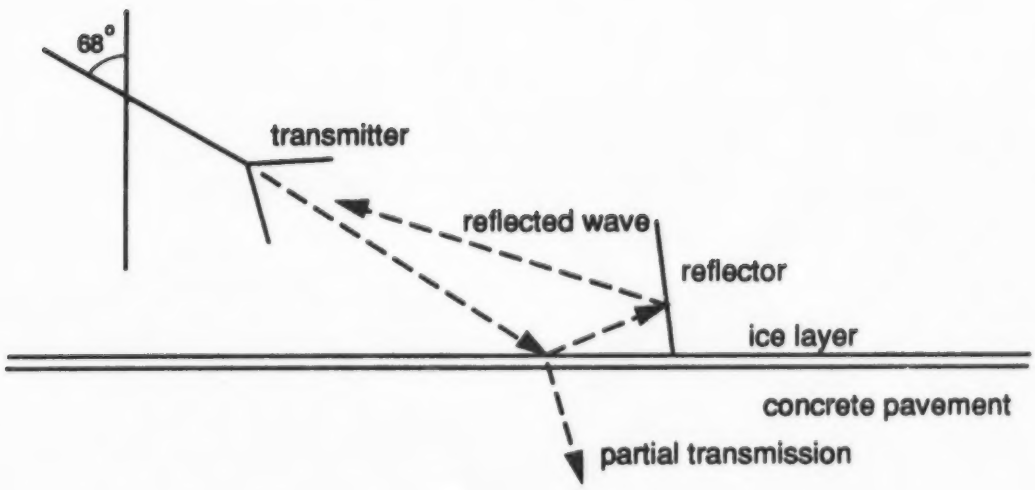
Since the police traffic control radars are already quite effective, it appears that this application could enjoy a high rate of success.

4.5/ Comparison of Probabilities of Success

In this section, we compare the Probabilities of Success for the different projects described in Section 4. The different projects are listed in Figure 4.6 and a five (1 - 5) point system is applied with the most likely successful projects being awarded 5 and the least likely projects being awarded 1.



(a)



(b)

Figure 4.5/ a) Transmission from air into concrete pavement at the Brewster angle

b) Partial reflection of the wave from the ice layer

		Evaluation				
Item	**Technique**	**1**	**2**	**3**	**4**	**5**
4.1	Geophysical Site Conditions		X			
4.2	Pre-engineering, Quality Assurance & Maintenance					
4.2.1	Pre-engineering Surveys					X
4.2.2	Quality Assurance					
4.2.2.1	End Result Evaluation				X	
4.2.2.2	Compaction of Asphalt				X	
4.2.2.3	Profile of Granular Materials				X	
4.2.3	Maintenance					
4.2.3.1	Detection of Deteriorated Joints					X
4.2.3.2	Detection of Voids or Frost Heaves					X
4.2.3.3	Detection of a Wash-out	X				
4.2.3.4	Detection of Cracks in Beams			X		
4.3	Weather Monitoring & Road Surface Conditions					
4.3.1	Identification of Icing	X				
4.3.2	Detection of White-out	X				
4.3.3	Identification of Roadbed			X		
4.3.4	Indentfying Buried Plastic Pipe		X			
4.4	Traffic Characteristics					
4.4.1	Traffic Counts			X		
4.4.2	Average Speed of Traffic					X
		1	2	3	4	5

Figure 4.6/ Comparison of Probabilities of Success

5/ Conclusions and Recommendations

5.1/ Conclusions

Radar is ideally suited for remote sensing in those areas where the electrical properties of the target are considerably different from the surrounding medium. In this report, we identify a number of these cases and explain how the measurements could be conducted. A comparison chart is provided in Figure 4.6 with an estimate of the relative Probabilities of Success.

It is concluded that there are many different possible applications of radar in highway design, construction and maintenance. Most of these can be related to the use of the impulse radar currently in-house at the Ministry or a relatively inexpensive CW radar which is commonly using by the police in traffic control.

The amount of additional effort in realizing an operational system for these different applications varies greatly since some techniques such as Detection of Cracks in Beams, Columns and Piers have never before been examined. Others such as Detection of Deteriorated Joints and Detection of Voids are closely related to the currently used DART and would require little additional effort for testing.

In general, it appears that the areas of Geophysical Site Evaluation; and Pre-engineering, Quality Assurance and Maintenance offer the most potential of success. Both Weather Monitoring and Road Surface Conditions; and Traffic Characteristics have numerous difficulties in operation and implementation. However, there is one possible application of CW radar similar to the type used for traffic control which may be useful in determining average speed of traffic and the typical mix of trucks and cars.

5.2/ Recommendations

It is recommended that in view of the fact that the measurements can be made with the existing Ministry radar, ar. investigation be conducted to further study the use of radar in evaluating:

1. Geophysical Site Conditions
2. Pre-engineering, Quality Assurance and Maintenance

In this second category, eight different applications are identified and six of these appear to be very promising.

Thus, it is recommended that on-site measurements be made to determine the actual waveforms that are encountered in practice.

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